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Reconstruction of postglacial landscape evolution within the eastern periphery of Chuya depression on the basis of multidisciplinary analysis of peats in Boguty river basin, SE Altai, Russia

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Abstract. This paper presents the results of multidisciplinary investigations of the peat-bed under hummocky permafrosted boggy meadow within the Boguty basin. For the last 7600 years 4 evolutionary phases of peatbog formation within the drained part of Low Boguty Lake bottom were established and corresponding 4 pollen complexes were described. 18 radiocarbon dates suggest some chronological bench marks of postglacial landscape evolution in the region. After degradation of Sartan glaciation about 14000 BP, trees grew in now forestless areas at 11000 BP and 8500-7800 BP. The climate in the first half of the Holocene was warmer and more humid. Accumulation of lacustrine loams within the studied peatbog occurred before 7600 BP with predominated algae Pediastrum, Zygnemataceae and Botryococcus. After the lake level lowered in the result of destructing moraine dam, two lower peat horizons were developed about 7600 – 7200 BP. An episode of significant lake desiccation (later than 7200 BP) was recorded in all proxy archives. Further rise of water supply led to increasing the number of water-bog plants, diatomaceous, euglenic and green algae. At the same time, the pollen of xerophytes began to predominate in the pollen complexes, indicating aridization. The final stage reflects stable peatbog drying and its transformation into boggy meadow, decomposition and mineralization of peat.

1. Introduction

In the framework of our multidisciplinary investigations of paleoenvironmental changes in the southeastern part of the Russian Altai (SE Altai), and in order to reconstruct the postglacial climatically driven landscape evolution within the eastern periphery of the Chuya intermountain depression, the hummocky permafrosted boggy meadow was studied in the high mountainous Boguty basin. This area bordering with the Mongolian Altai is significantly less investigated in comparison with central parts of the Chuya depression – the largest intermountain basin in the SE Altai. In addition to the first geological and geomorphological studies [1, 2], archaeological sites of Paleolithic

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time, Late Bronze Age and Iron Epoch are described here (brief review is given in [3]). It makes multidisciplinary regional investigations, including presented in this paper analysis of peatbog, relevant also for reconstructing the Holocene chronology and paleoenvironmental context of nomadic societies settling in this high-mountain area.

2. Study area

The Boguty river belongs to the basin of the Chuya river - the main water artery of the SE Altai. The Boguty river basin (about 35 km long) includes a part of western slope of the Chikhachev range and small (about 25x13 km) Boguty depression, which forms an eastern periphery of the Chuya intermountain depression (figure 1). The Chikhachev range stretches in south-north direction at about 100 km, and has maximal altitudes up to 4029 m a.s.l. in its southern part. Within the Boguty basin maximal altitudes are about 3550-3700 m a.s.l. Beginning in the axial part of the ridge, the Right and Left Boguty at their confluence form the Boguty river. Downstream, within the Boguty depression, the Boguty river connected three largest lakes in its basin – Upper Boguty (or Boguty according some maps), Middle Boguty (or Aday) and Low Boguty (or Kok-Kul).

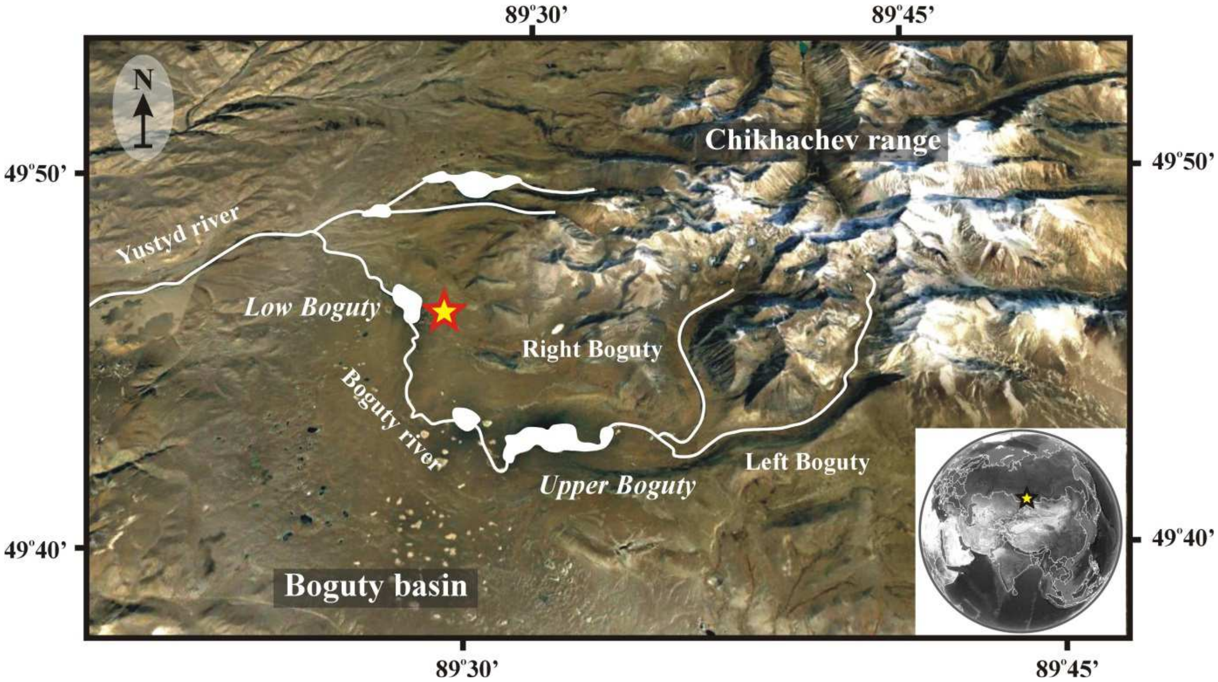

Figure 1. Boguty basin. Star shows the location of studied peatbog.

The area is characterized by extreme ultra continental cryoarid permafrost affected environment. Within the Boguty basin mountain steppe is changing with height into tundra-steppe and tundra vegetation. The forests, which have an insular distribution in the western mountains flanking the Chuya depression, are completely vanishing in its eastern periphery, and there is no forest vegetation at all within the studied area. The higher topographic belt is represented by alpine landscapes and glacial zone. The modern glaciation within the axial parts of the ridges is practically completely degraded [4].

In the Late Pleistocene the western slope of the Chikhachev range and adjusted Boguty depression were occupied by ice-sheet. Its degradation was accompanied by formation of terminal moraine complexes and moraine-dammed lakes. Further destruction of dams was followed by water level lowering and fluvial system transformation, as well as by developing thermokarst lakes and peatbogs within drying bottom of the basin and by spreading vegetation in it.

The studied peatbog is located in the eastern part of the depression occupied by moraine-dammed Lake Low Boguty (water edge about 2387 m a.s.l.) in the proximal part of the debris cone of a short right tributary of the Boguty river. Repeated debris flows passed along this tributary valley during the Holocene [5]. Wash out and erosion of the eastern lake shore resulted in natural outcrops formation. One of these outcrops, about 70 cm high, was studied using different methods.

3. Methods

Pedostratigraphy and field morphology of peats and underlying lacustrine deposits were described in a shore-lake outcrop; pollen analysis and complex group analysis of biological composition were carried out for reconstructing paleoenvironmental conditions and sedimentation patterns.

Samples for pollen analysis were prepared applying the standard procedure [6]. Pollen and spores were identified using a microscope with 400x magnification. Microphotography of preparations was performed with a CarlZeiss Axioskop. Pollen percentages were calculated based on the tree and herbs pollen sum. Registering spores and other non-pollen palynomorphes during pollen analysis widen paleoecological abilities of the method. Thus, the registered stomata give an additional information on distribution of tree vegetation in the immediate vicinity of the section; finds of fungi (Glomus) are indirect indicators of enhanced drainage (bog – meadow transition).

Method of group analysis of biological composition was initially developed for lacustrine deposits (gyttja) [7] and later was supplemented and successfully approved for other water-related environments [8]. Water suspension of native sample is analyzed under microscope (X280-400); all encountered remnants of flora and fauna (fragments of vascular plants, cists and skeletons of algae, sponge spicules etc.) are identified up to the lowest possible taxonomic level.

The species composition of forest vegetation from charcoal fragments was determined by V.S. Myglan, Siberian Federal University, Krasnoyarsk, Russia.

Litho-stratigraphic and morphological pedogenetic descriptions were provided following FAO guidelines for soil description [9]. The presented profile within the studied peatbog was classified in terms of World Reference Base for Soil Resources [10].

Detailed geomorphological investigations and process analyses were based on interpretation of aerial photographs, Landsat-TM images, topographic maps (1:50000), and field investigations including mapping of landforms and deposits of different genesis.

The selected exposures were studied to examine the sediments and landforms associations. Suitable material from key locations was sampled for determining the radiocarbon chronology of the climate changes and landscape evolution.

The radiocarbon ages were measured at the Cenozoic Geochronology Center SB RAS, Novosibirsk, and at the Institute of Geography RAS, Moscow, applying the standard method [11]. The conventional radiocarbon ages were calibrated (2-sigma standard deviation) applying the CALIB Rev 7.0.4 program [12], with the IntCal13 calibration data set [13].

4. Results

4.1. *Profile horizontation and morphology*. Hummocky permafrosted boggy meadow (66 cm of peat layers) was described under mesic herbaceous sedge-grass vegetation (Poaceae sp., Carex sp., Gentiana tenella Rottb., Potentilla sericea, Dendranthema zawadskii (Herb) Tzvel, Paraquilegia microphylla (Royle) Drumm. Et Hutch). The terrain has naturally drained being recently cut by a new branch of a rivulet delta. Thus, the peat has run dried and started to degradate. The profile includes 7 horizons. The upper one is humified sodded peat. It is followed by five peaty horizons varying in color, texture and structure (or its absence), in degree of humification, in proportion of mineral admixture. Lacustrine silty loam underlies peat (figure 2).

Following horizons were described: **1)** Ha1 0-12 cm strongly decomposed peat (sapric material), with a considerable share of minerogenic components (sandy loam), moist, 7,5YR 2/2 brownish black, weak subangular blocky structure, root-interlaced sod; **2)** H2a 12-19cm an alternation of 1 cm interlayers: strongly decomposed (hemic) 7,5 YR 4/2 grayish brown and moderately decomposed (fibric), 7,5 YR 3/3 dark brown. Both contain little admixture of fine grained sand. Moist. **3)** H3a@ 19-30(34) cm moderate to strongly humified peat, cryoturbated, slightly moist to moist, 7,5YR 3/4 dark brown weak mostly subangular blocky structure; **4)** H4a,@ 30 (34)-47 cm very strongly humified, slightly moist, 7,5 YR 2/3 very dark brown. It is very loose and comparatively well structured; the structure is subangular-blocky; **5)** H5 47-55 cm weakly humified fibric peat, laminated, compressed, moist, 5YR4/4 dull reddish brown; **6)** H6@ 55-58(66) cm moderately to weakly humified peat, slightly moist, 7,5YR 2/3 very dark brown, loose, earthy; turbated: with small wedges; **7)** Lg 58(66) cm and deeper lacustrine silty loam, wet, 5Y 4/1 gray, 4/2 grayish olive, schlieren texture, moderately developed granular cryogenic structure, thixotropic. High ice content permafrost occurs below 71 cm.

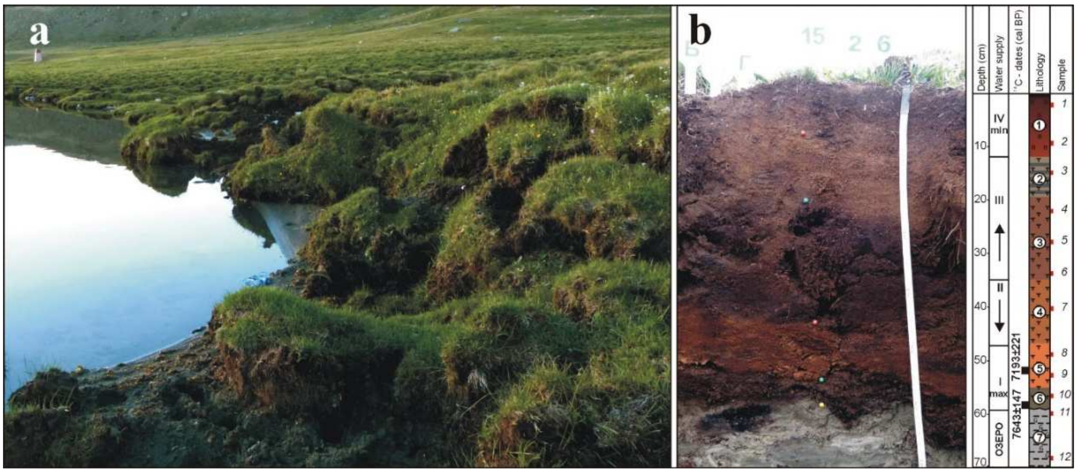

Figure 2. Hummocky permafrosted boggy meadow near Lake Low Boguty. Photo (a) and studied section (b).

4.2. *Group analysis of biological composition.* The group analysis of biological composition conducted for 7 peat samples has allowed getting data on ecology of a local lacustrine-boggy system and to discriminate four evolutionary phases since the peatbog formation within the former lake bottom (figure 2). This was a result of cutting a moraine dam and dropping the level of Lake Low Boguty earlier 7600 BP.

Phase 1: The peaty material at the depth of 50 – 65 cm (**horizons 5, and 6**) was accumulated in a shallow lake within in-shore zone overgrown with water-bog plants and hypnum mosses. They gave refuge to a wide variety of diatoms (27-94% of the whole residues' sum) and yellow-green algae *(Chrysophytha* sp.) (1-1.5%). Attached forms prevail among the diatoms (about 93% of the diatoms' sum); *Fragilaria* (65%) and *Diatoma* (27%) are dominants. Representatives of benthic algae compose only 3%. A few fragments of sponges indicate a weak flowage in the lake in the relative time.

Phase 2: The peat at the depth of 36 – 47 cm (**horizon 4**) does not contain algae, water-bog plants appear in small amounts. This could be an evidence of an open water disappearance. Vascular plants' residues are represented mostly by roots of sedges. Dwarf birch (*Betula fruticosa* Pall) appears.

Phase 3: The peat at the depth 12-36 cm (**horizons 2, and 3**) was formed in conditions of better water supply. Water-bog plants got more abundant at 30-36 cm (**horizon 3**). Sums of diatoms and euglenales rise up to 8%. Residues of grasses (Poaceae) took place along with sedges (Cyperaceae).

Phase 4: The deposits in the upper 6 cm of the section (**upper part of the horizon 1**) were accumulated under sedge-grass-herbaceous boggy meadow. Diatoms have nearly disappeared. Half of those which still occur is typical for boggy environment (*Pinnularia*), others (*Hantzschia amphioxis*) can inhabit soils.

4.3. *Pollen analysis.* In total, 12 samples from silty loam (2) and peat (10) deposits were collected for the analysis of palynomorphs. Four pollen complexes were established (figure 3). Their boundaries were determined by changing of dominant taxa. The lower complex (1) characterizes landscapes and vegetation during lacustrine sedimentation, all other complexes (2-4) – evolution of regional and local vegetation during subaerial peat accumulation. The description below is given from bottom to top.

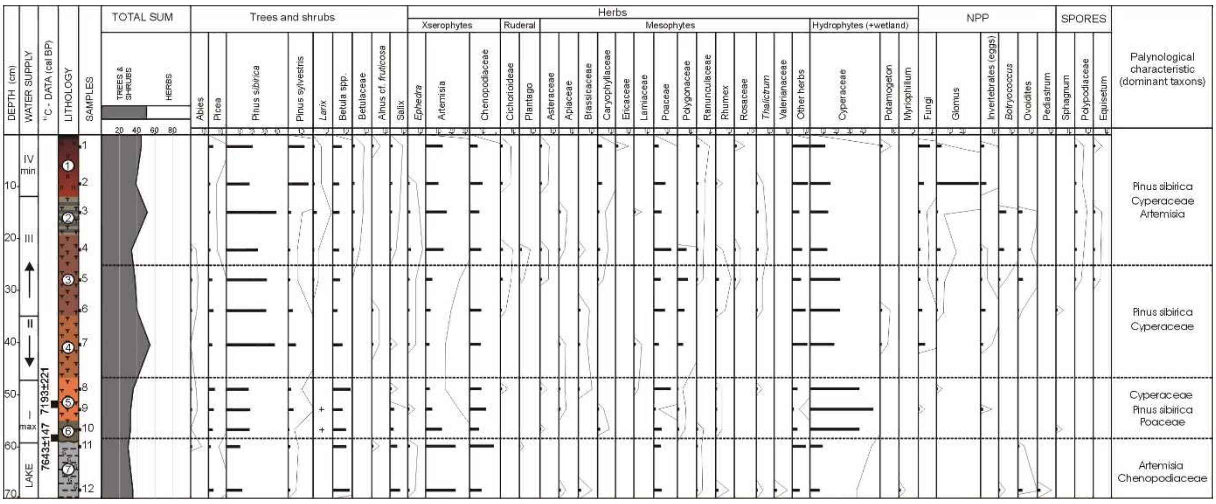

Figure 3. Pollen diagram,lithology and sample position in the studied section.

Pollen complex 1: olive-grey lacustrine clay with organic lenses at the depth 58 – 70 cm (samples 11, 12, **horizon 7**). The spectra of this zone are characterized by high contents of various herbs pollen (>60%). The dominance of *Artemisia* spp. and Chenopodiaceae is typical for pollen complex 1. Pollen percentage of trees and shrubs is about 30-35% and consist of *Betula* spp., *Pinus* spp., *Pinus sibirica* Du Tour, *Salix*, *Picea*. Percentage of microphytoplankton is low and presented by *Pediastrum*, *Spirogyra*, Zygnemataceae and *Botryococcus*.

Pollen complex 2: Peat of **horizons 5 and 6** (48 – 58 cm, samples 8 – 10). This complex is dominated by herbs pollen too. Among the herbaceous taxa the contribution of Cyperaceae increases. Trees and shrubs pollen are presented by *Pinus sibirica*, *Betula*, *Picea*, *Pinus sylvestris* L. The coniferous stomata were found in the samples 9 and 10 (figure 4).

Figure 4. Coniferous stomata discovered in the samples 9 and 10.

Pollen complex 3: Peat of **horizons 3 and 4** (25 – 48 cm, samples 7 – 5). The complex is characterized by dominance of Cyperaceae and *Pinus sibirica* pollen. Non-pollen palynomorphs are also presented in spectra (fungal spores and hyphae, *Glomus* particulary, eggs of invertebrate). Pollen grains of *Larix* were determined in the sample 5, as well as few remains of algae – Spirogyra and Botryococcus.

Pollen complex 4: Peat, decomposed peat with minerogenic components, and humus of **horizons 1, 2, and 3** (0 – 25 cm (samples. 4 – 1)). The uppermost spectrum of the complex 4 is characterized by an approximately equal amount of trees and herbs pollen. Among the herbaceous taxa the contribution of *Artemisia* increases (up to 20%). *Larix* pollen is presented in all samples of this interval.

4.4. Radiocarbon analysis

Radiocarbon ages of two lower peat horizons at 57 – 67 and 50 – 57 cm were obtained – 7643±147 cal BP (IGAN 4823) and 7193±221 cal BP (IGAN 4825) respectively. Sixteen more radiocarbon ages of organic material from deposits of various geneses within the Boguty basin [5, 14] cover time interval 14000 – 300 cal BP and suggest some chronological bench marks of climatically driven landscape evolution in the region.

5. Reconstructions of the local lacustrine-boggy system transformation, climate changes and landscape evolution

Multidisciplinary investigations in the Boguty basin with the main focus on surroundings of Lake Low Boguty allowed reconstructing paleoenvironmental conditions, which were preceded the peatbog formation. The age of paleopeat with fragments of tree and bush vegetation discovered in the head of the tributary valley near Lake Low Boguty argues for complete degradation of Sartan glaciation or significant glaciers retreat (above 2500 m a.s.l., the altitude of paleopeat location) within the eastern periphery of the Chuya intermountain depression at about 14000 BP [14]. The fossil forest soils of about 11000 BP and charcoal (*Larix*) fragments (8500-7800 BP) indicate the prolonged period of developing forest vegetation in this part of the Boguty basin. Thus, it could be stated that the climate in the first half of the Holocene in the SE Altai was warmer and more humid in comparison with the modern one. Forest vegetation occupied contemporarily treeless areas, including slopes of the Boguty depression.

Accumulation of lacustrine loams at the bottom of the studied peatbog took place before 7600 BP. Freshwater algae *Pediastrum, Spirogyra* and *Botryococcus* settled in the lake at that time. The plant communities were dominated by *Artemisia* spp. and Chenopodiaceae. The lake was more extensive (up to 2400 m a.s.l.) and most likely it was surrounded by open landscapes, despite the presence of tree and shrubby vegetation (up to 30-35% in pollen spectra) - *Betula* spp., *Pinus* spp., and single *Pinus sibirica, Salix, Picea* (figure 3). It is interesting that *Larix* pollen was not found in the analyzed samples of lacustrine deposits, although fragments of larch charcoals with the age of 8500 – 7800 BP were collected from buried soils not more than 1 km upstream the tributary valley from the studied section. The absence of *Larix* pollen could be explained by both local distribution of larches or erosion (washing out) the upper part of the lacustrine deposits in the result of subsequent lowering of the lake level.

After the lake level lowering, which was associated with cutting the moraine dam, within the lake littoral, settled by higher water-bog plants and hypnum mosses with a diverse diatom flora, two lower peat horizons were developing about 7600 – 7200 BP. The presence of coniferous stomata in these horizons is an evidence of growing tree vegetation near the section at that time. The episode of significant lowering of the water edge, occurred later than 7200 BP, is recorded in all proxy archives – in sedimentary record (horizon 4), in biological composition of plant remnants (phase 2), and is also displayed in pollen spectra by appearance of non-pollen palynomorphs (fungal spores and hyphae of *Glomus*, eggs of invertebrate).

The subsequent improvement in the water supply of the peatbog (horizons 3, 2; phase 3) leads to increasing the number of water-bog plants, diatomaceous, euglenales and green algae. However, already at this time the vegetation in the lake surrounding reflects the enhanced aridity. The pollen of xerophytes, indicators of steppe landscapes, begins to predominate in the pollen spectra. Finally, the upper horizon of the section corresponds to the stage of stable peatbog draining, and its transformation into boggy meadow. Further radiocarbon dating of upper peat horizons will allow correlating periods of enhanced aridity, revealed from peat deposits of the Boguty basin, with the same periods recorded in pedosedimentary records of the SE Altai and SW Tuva [14, 15].

Generally, observed fluctuations of water supply in the lacustrine-boggy system within the Boguty basin may be associated with the stadial advances of mountain glaciers in the second half of the Holocene established for the SE Altai [16, 17]. Palynological data indicate that during all stages of peatbog developing water and fen plants (sedges, reeds, rdest etc.) were representatives of local vegetation around and within the lake. Among herbaceous vegetation, both xerophytes (*Artemisia*, *Ephedra*, Chenopodiaceae) and mesophytic plants were widely distributed. Pollen of trees and shrubs (mainly coniferous and to a lesser degree birch and shrub alder) is significantly represented in pollen spectra and may indicate spreading of forest vegetation within the study area. This thesis is also supported by presence of coniferous stomata in two lowest peat horizons, as well as heavy *Larix* pollen in three upper horizons. Perhaps the tree vegetation in the last 7000 – 8000 years, until its complete vanishing, was only locally distributed in the Boguty basin. Buried forest soils and charcoals of younger age were not discovered within the study area.

Presented multidisciplinary investigations of peats in the Boguty river basin are in good agreement with the results obtained by Blyakharchuk et al [18] in the course of palynological analysis of cores from Grusha and Akhol Lakes, located within neighboring areas of the SW Tuva at the foot of the opposite slope of the Chikhachev range.

Acknowledgment

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